Development of Double-Pulsed Two-Micron Laser for Atmospheric Carbon Dioxide Measurements

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Abstract: A CO_2 lidar double-pulse two-micron high-energy transmitter, tuned to on- and off-line absorption wavelengths, has been developed. Transmitter operation and performance has been verified on ground and airborne platform.
OCIS codes: (140.3538) Laser, pulsed; (040.3060) Infrared; (280.1910) DIAL, differential absorption lidar

1. Introduction

There is a great urgency to comprehend the process of carbon dioxide (CO_2) exchange in the context of global climate change. Knowledge of the spatial and temporal distribution of CO_2, natural and man-made sources and sinks and transport in a global scale is crucial to predict and possibly manage the carbon cycle process. In response to these challenges, laser-based active remote sensing instruments are being developed. Researchers at NASA Langley Research Center (LaRC) have been looking at this problem and have implemented a 2-μm laser transmitter, initially designed for wind coherent Doppler lidar, to measure CO_2 concentration using integrated path differential absorption (IPDA) lidar [1]. The attractive feature of this laser is the long upper-level lifetime of the Hm:To:YLF active material. As a result it can produce two or more consecutive pulses within few hundred microsecond with a single pump pulse. This is an important feature in terms of overall transmitter design simplicity and efficiency.

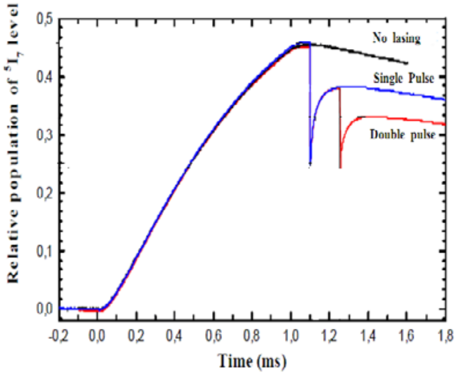
The 2-μm wavelength has a favorable weighting function near ground surface [2]. The R30 CO_2 line at 2050.967 nm (4875.75 cm^{-1}) is selected for its temperature insensitivity, absorption strength and lower interference from water vapor [2]. Active remote sensing using IPDA lidar is suitable for monitoring different atmospheric trace gases [1-2]. The technique relies on the differentiation between strong and weak absorbing features of the gas to be monitored defined as the on-line and off-line wavelengths, respectively. A high energy laser transmitter provides strong return signals for IPDA and results in high signal-to-noise ratio, which significantly enhances CO_2 measurement sensitivity and accuracy [2].

2. Two-Micron Lidar Transmitter Development

The 2-μm IPDA lidar laser transmitter consists of a Ho:Tm:YLF crystal based oscillator operating in a double-pulsed mode. A wavelength control system generates two different frequencies spaced by 200 μsec in time for injection seeding. In Ho:Tm:YLF crystal, Tm ions are excited with 792 nm radiation from $^3H_6$ to $^3H_4$ [3]. A 6% Tm concentration is selected to secure self-quenching that warrants a quantum efficiency close to 2. Thus, for every photon absorbed in the Tm $^3H_4$, two ions are deposited in the Tm $^3F_4$ manifold. Energy is then transferred from $^3F_4$ to Ho $^5I_7$ and the 2-μm laser transition occurs between the Ho $^5I_7$ and $^5I_8$. Since the Tm is not directly involved in the actual 2-μm emission, the energy in the $^3F_4$ serves as a reservoir to repopulate the Ho.

For applications where two laser pulses are required, other lidar systems are forced to use either two lasers or pump twice. Ho:Tm:YLF operates much more efficiently in double pulse format than single pulse. The energy store in Tm, produced by a single pump, has long lifetime sufficient to pump and repopulate Ho continuously enabling a second pulse, as shown in Fig. 1a. The second pulse is then extracted by simply re-opening the Q-switch without costing additional pump energy. This process takes about 150μs and results in the recovery of 50% of the depleted population. It has been shown that the energy ratio of the two pulses can be adjusted by controlling the first Q-switch time with respect to the pump pulse. Fig. 1b lists laser parameters for the CO_2 IPDA lidar transmitter.

Transmitter seeding is obtained through a wavelength control system. This system consists of three continuous-wave seed lasers. One is locked to the CO_2 absorption center line though a pressure-controlled gas cell, in which the pressure is maintained at 5 torr to narrow the absorption line width for better discrimination. The second seed laser is offset by 2 to 6 GHz from the absorption center and used as the on-line. The third laser is locked with a wavelength meter and used as off-line reference. A fiber based switch alternates the two seed wavelengths and the beams are routed for seeding the power oscillator. The two output pulses from the power oscillator have transform limited line-width. The laser transmitter has a 3 m long ring architecture and is housed in a sealed enclosure purged with dry air. The optical bench temperature is controlled to avoid any thermally induced misalignment. All the optical mounts are designed to be adjustable, lockable and hardened to withstand vibrations that can occur in ground or airborne operation. The overall dimension of the laser enclosure is 67×16.5×26 cm^3.



(a)

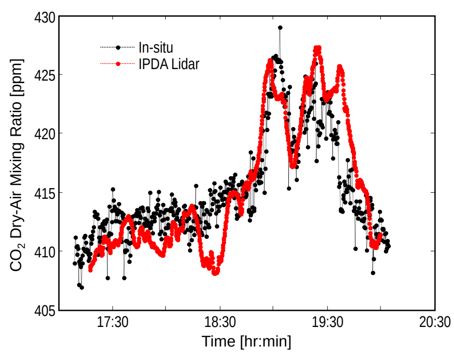
Wavelength;	Off-Line	2051.2500 nm
	On-Line	Tunable
Pulse Energy (On/Off)		90/45 mJ
Pulse Width (On/Off)		200/350 ns
Freq. Control Accuracy (On/Off)		0.3/30 MHz
Pulse Spectral Width (On/Off-Line)		2.2/1.3 MHz
Repetition Rate		10 Hz
Beam Quality (M^2)		2
Beam Divergence		150 µrad
Beam Diameter		21.4 mm
Wall-Plug Efficiency		1.4%
Beam Expansion		×6

(b)

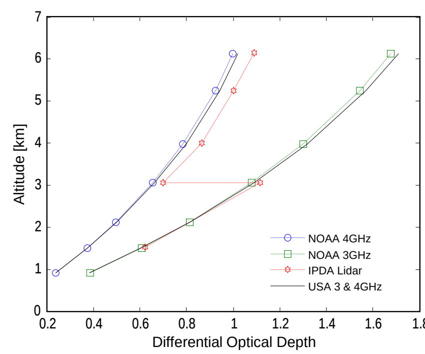
Fig. 1. (a) Relative population of the Ho upper laser level in three distinct conditions for 1 ms pumps. (b) Main parameters list of the 2-µm IPDA lidar laser transmitter.

3. Transmitter Validation

The double-pulse laser was integrated into an airborne CO_2 IPDA lidar. The 2-µm IPDA was validated for CO_2 differential optical depth measurement [2]. Validation experiments included ground operations with calibrated targets at 860 m away from the instrument and compared with *in-situ* CO_2 sensor, as shown in Fig. 2a. Airborne validation was conducted by integrating the IPDA in NASA B-200 aircraft. Fig.2b compares the 2-µm lidar CO_2 optical depth measurements with optical depth driven from NOAA air sampling results, conducted at the same location and altitudes.



(a)



(b)

Fig. 2. CO_2 2-µm IPDA lidar (a) Ground and (b) airborne validation [1-4].

4. Conclusion

Double-pulsed, 2-µm IPDA lidar is suitable for CO_2 optical depth measurements. The laser transmitter is a key component of this instrument. This 2-µm laser is capable of producing two successive pulses, with independent wavelength tuning and locking. Ground and airborne validation experiments indicated the IPDA sensitivity to atmospheric CO_2. This instrument has the potential to enhance both spatial and temporal resolution for CO_2 global measurement during day and night.

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5. References

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